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QUANTITATIVE EXPERIMENTS IN RADIOTELEGRAPHIC TRANSMISSION

By L. W. Austin

The testing of the recently erected high-power United States naval radiotelegraphic station at Arlington, Va., has given another opportunity for carrying out experiments on the relation between the currents in sending and receiving antennas at various distances, and at the same time for investigating the relative advantages of transmission by means of damped and continuous oscillations.

The work of the Navy Department on quantitative long-distance transmission was begun in 1909, and during the autumn of that year and in 1910 experiments were carried on between the Brant Rock Station and the scout cruisers *Birmingham* and *Salem*. An account of this work was published in the Bulletin of the Bureau of Standards.[1]

The results of the experiments were expressed by the empirical formula [2]

$$(1) \qquad I_R = 4.25 \frac{h_1 h_2 I_s}{\lambda d} \cdot e^{-\frac{0.0015d}{\sqrt{\lambda}}}$$

where I_R is the received antenna current through a resistance of 25 ohms, I_S the sending current, h_1 and h_2 the full heights of the sending and receiving flat top antennas respectively, λ the wave length, and d the distance between the stations, the currents being given in amperes and the lengths in kilometers. The expression is applicable only to day [3] communication over salt water. This formula was not expected to give highly accurate results, since the receiving resistance was taken arbitrarily as 25 ohms, which is too high for the shorter wave lengths and too low for the longer ones. It has, however, amply proved its usefulness as a practical expression for determining the range of communication between stations, and indicates with a fairly close degree of approximation the strength of signals which may be expected at any distance, at least up to 2000 miles (3700 km).

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[1] This Bulletin, 7, p. 315, 1911, Scientific Paper 159; Jahrbuch der drahtlosen Telegraphie, 5, p. 75, 1912.

[2] In formula (1) h denotes the total height of the flat-top antenna as in the former article. In all other cases in this paper h is the effective height of the antenna; that is, one-half the length of the equivalent Hertzian oscillator.

[3] Day signals are, in general, fairly uniform in their intensity. Night signals are usually stronger but are so irregular in intensity that it has not been found possible to represent them by any quantitative expression

In 1909, Sommerfeld [4] gave a theoretical treatment of the transmission of electrical waves over a plane perfectly conducting surface placed in the equatorial plane of a Hertzian oscillator. This theoretical work has been carried further by H. Poincaré,[5] J. W. Nicholson,[6] H. March,[7] and W. von Rybczynski.[8] Without discussing this work in detail the results may be stated in the following formula for the electric amplitude E.

$$E = 120\pi \frac{hI_s}{\lambda d}\sqrt{\frac{\theta}{\sin\theta}}\cdot e^{-\frac{0.0019d}{\sqrt[3]{\lambda}}} \tag{2}$$

This formula may be analyzed into three parts. The first, $120\pi\frac{hI_s}{\lambda d}$, where h represents the effective height[9] to the center of capacity of the sending antenna, λ the wave length, I_s the current at the base of the sending antenna, and d the distance to the point under consideration, is simply the Hertzian expression for the electric field produced at a distance d in the equatorial plane of an equivalent oscillator of length $2h$. It is supposed in this expression that the distance d amounts to a large number of wave lengths. The expression $\sqrt{\frac{\theta}{\sin\theta}}$ takes account of the curvature of the earth, θ representing the angle under which the distance d appears from the center of the earth. For purposes of calculation the expression may be considered equal to unity for all distances as yet covered by day transmission.

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[4] A. Sommerfeld, Ann. der Phys., **28**, p. 665; 1909.

[5] H. Poincaré, Jahrb. d drahtl. Teleg., **3**, p. 445; 1910.

[6] J. W. Nicholson, Phil. Mag., **21**, p. 281. 1911.

[7] H. March, Ann, d Phys., **37**, p. 29; 1912.

[8] W. von Rybczynski, Ann. d Phys., **41**, p. 191; 1913. See also J. Zenneck, Lehrbuch der drahtlosen Telegraphie, p. 294.

[9] If the earth is perfectly conducting and there are no metal masses near the antenna affecting the field distribution, h should equal the height to the center of capacity, and is so used except when special experiments showed the effective height to be less.

The final expression, the scattering term, $e^{-\frac{0.0019d}{\sqrt[3]{\lambda}}}$ gives the losses due to the escape of energy into the upper atmosphere on account of the failure of the waves to follow perfectly the curvature of the earth. In this theoretical formula (2) the electric field will be expressed in volts per kilometer if I_s is expressed in amperes and all the lengths in kilometers. The equation is developed on the assumption of a perfectly conducting earth. According to von Rybczynski [10] a slight departure from perfect conductivity will produce a slight increase in the receiving field strength, apparently on account of a diminution in the value of the scattering factor. If the conductivity of the surface becomes still poorer, however, an absorption term [11] would have to be introduced, as it is well known that the electrical waves are considerably absorbed in passing over land in most localities.

If the waves under consideration are undamped, the current in the receiving antenna is

$$I_R = \frac{Eh_2}{R} = 377\frac{h_1h_2I_s}{\lambda dR} \cdot e^{-\frac{0.0019d}{\sqrt[3]{\lambda}}} \tag{3}$$

h_2 represents the effective height to the center of capacity of the receiving antenna, expressed in kilometers, and R the high frequency resistance of the receiving system. In the case of damped oscillations, on account of the form of the wave train of oncoming oscillations, the value of the received current

$$I_R = \frac{Eh_2}{R\sqrt{1+\frac{\delta_1}{\delta_2}}} = 377\frac{h_1h_2I_s}{\lambda dR\sqrt{1+\frac{\delta_1}{\delta_2}}} \cdot e^{-\frac{0.0019d}{\sqrt[3]{\lambda}}} \tag{4}$$

where δ_1 and δ_2 are the decrements of the sending and receiving systems.

It is of course of the greatest importance to determine whether the actual observations on received current agree with the theoretical formula, both regarding the Hertzian term and the scattering term. The Brant Rock experiments did not conclusively settle these questions, especially the latter, as the greatest distance in the experiments, 1000 miles (1850 km) was too short, considering the errors of observation. Von Rybczynski in his article gives a curve in which the Brant Rock observed values are shown to agree more perfectly with the theoretical formula than with the empirical formula. Unfortunately, however, the observations chosen by him were among the earliest and least accurate in the series of experiments.

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[10] Ann. d Phys., 41, p. 208; 1913.

[11] See J. Zenneck, Ann. d Phys., 23, p. 846, 1907; A. Sommerfeld, Ann. d Phys., 28, p. 665, 1909; J. Zenneck, Lehrb. d drahtl. Teleg., p. 297.

The high-power station at Arlington, Va., was equipped by the National Electric Signaling Co. with a 100-kw rotary gap sending set, and was intended for communication with the Canal Zone and with the fleet in the North Atlantic Ocean. The original plan for the antenna as submitted by the National Electric Signaling Co. showed an umbrella supported by a single tower 600 feet (182 m) high. The experiments at Brant Rock, however, showed the experts of the Navy Department that an umbrella antenna gave a center of capacity too low for the most effective working unless a very high mast and a large tract of ground were used. For this reason the Arlington station has been supplied with a platform antenna supported by three towers about 120 m between centers, one being 600 feet (182 m) high and the other two 450 feet (137 m). The antenna has been put up in sections and consists of two flat top antennas 350 feet (106 m) long and one 313 feet (96 m) long. These are 88 feet (26.8 m) wide with 23 wires each. The triangular space between the flat tops was filled in with a triangular fan.[12] of 25 wires supported independently of the flat top sections. The vertical portion of the antenna consisted of a fan of 23 wires, narrowing down to a point at 23 m above the earth, from which the wires are brought down in a cage of the Fessenden type. The capacity of this antenna is 0.010 μf, its natural wave length approximately 2100 m, and its height to the center of capacity 122 m. The ground system consists of a radiating net work of wires covering the space between the triangle of towers and extending to some distance outside. The towers were built so that they were insulated from the earth with switches by which they could be connected to the ground net system. With the towers insulated, the antenna resistance, exclusive of the inductance, at a wave length of 4000 m is approximately 8 ohms. Grounding the towers reduces the resistance to

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[12] At the close of the Salem experiments this fan was removed, as its swaying at times rendered the tuning slightly uncertain.

1.8 ohms, and curiously enough no perceptible difference in capacity is observed, nor is the natural period changed by more than a few meters. Theoretically it is difficult to understand how this great difference in antenna resistance can be produced without changing the field distribution so as to vary the capacity and wave length; but more remarkable still it is found that the ratio between the current in a receiving antenna a few miles distant and the sending current at Arlington remains unchanged whether the towers are grounded or insulated. Since the sending current with the towers grounded is much larger than with the towers insulated, they are always kept grounded. The receiving at Arlington is practically the same whether the towers are grounded or ungrounded. The decrement of the emitted waves at 3800 m is approximately 0.05.

SHORT-RANGE EXPERIMENTS

Short-range experiments have been made between several receiving stations near Washington, using the high-power station at Arlington and the station at the Washington Navy Yard for sending. For calculating the received current at these distances only the first part of the theoretical formula (4) need be used. The received current should then be

$$I_R = 377 \frac{h_1 h_2 I_s}{\lambda d R \sqrt{1 + \frac{\delta_1}{\delta_2}}} \tag{4'}$$

In this case the lengths may be taken in any corresponding units since they occur an equal number of times in numerator and denominator. The receiving current was measured by thermoelements or thermomilliammeters.

Table 1 gives the results of these observations. The column of calculated values contains those derived from equation (4′), where the length of the equivalent oscillator is assumed to be twice the height [13] to the center of capacity. All these observations indicate that the length of the equivalent oscillator is in these cases not greater than the height to the center of capacity of the sending antenna, and in some cases is less.[14] This may be due to the shape of the antennas, or, to the fact that the earth is not properly conducting as assumed in the theory. At Arlington there is undoubtedly some loss in the steel towers. The Washington Navy Yard station has its antenna supported by a wooden mast and a brick chimney in which there can be no losses; the ground, however, is not ideal.

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[13] Zenneck, Lehrbuch d. drahtlose Telegraphie, p. 46. In some earlier publications, J. Washn Acad., 1, p. 275, 1911, and Proc. Amer. Phil. Soc., 52, 210, p. 407, 1913, I have assumed the length of the equivalent oscillator to be $h\sqrt{2}$ instead of 2h. (See R. Ruedenberg, Ann. der Phys., 25, p. 446, 1908.) I have become convinced, however, that for the theoretical calculation of the electric field produced by the radiation, the equivalent length of the oscillator should be l=2h.

TABLE 1

Short-Range Experiments

Sending station	Receiving station	λ meters	I_s amp.	Distance		h_1 meters	h_2 meters	R ohms	Received current 10^{-3} amp.		$\frac{\text{Obs.}}{\text{Cal.}}$
				Miles	Km				Obs.	Cal.	
Arlington...	Bureau of Standards.	3800	102	4.2	7.8	122	30	275	5.8	15.8	0.37
Do.....	Capitol..............	3800	102	3.45	6.4	122	36	294	8.5	21.5	.40
Do.....	Navy yard............	3800	102	3.9	7.2	122	36	282	9.3	19.9	.47
Navy yard..	Bureau of Standards.	1000	12.2	5.4	10.0	36	30	71	3.2	7.3	.44
Do.....	Capitol..............	1000	12.2	1.05	1.9	36	36	181	7.4	18.5	.40
Do.....	Bureau of Standards.	2800	7.0	5.4	10.0	36	30	70	0.55	1.07	.51
Do.....	Arlington............	2800	7.0	3.9	7.2	36	122	9.3	22.0	46.2	.48

LONG-DISTANCE OBSERVATIONS

During the months of February and March, 1913, the cruiser Salem was sent on a voyage to Gibraltar for the purpose of carrying out tests with the Arlington station. Shunted telephone observations were taken in the day time up to 1920 nautical miles (3550 km), while with the Fessenden heterodyne messages were read by day up to 2100 nautical miles (3880 km). The wave length used by Arlington was 3800 meters and the average sending current was 100 amperes.[15]

The height of the Arlington antenna to the center of the horizontal portion is 470 feet (143 m) and the height to the center of capacity 400 feet (122 m). The height to the flat top of the Salem's antenna was 130 feet (39.6 m), the height to the center of capacity being 114 feet (34.5 m).

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[14] According to the results of M. Reich (Physik. Zs., 4, p. 934, 1913), under favorable circumstances the theoretical value is more nearly approached than in my observations.

[15] The original ammeter reading in the antenna was 110 amperes, but a later calibration of the instrument showed that this was somewhat too large.

The results of the observations with the electrolytic detector are shown in Fig. 1. The observed values of the received currents are indicated by crosses, and were calculated from the audibility measurements made by the shunted telephone method on the electrolytic detector in exactly the same way as in the Brant Rock experiments, except that on account of the increased sensitiveness of the telephones, the least audible antenna current was

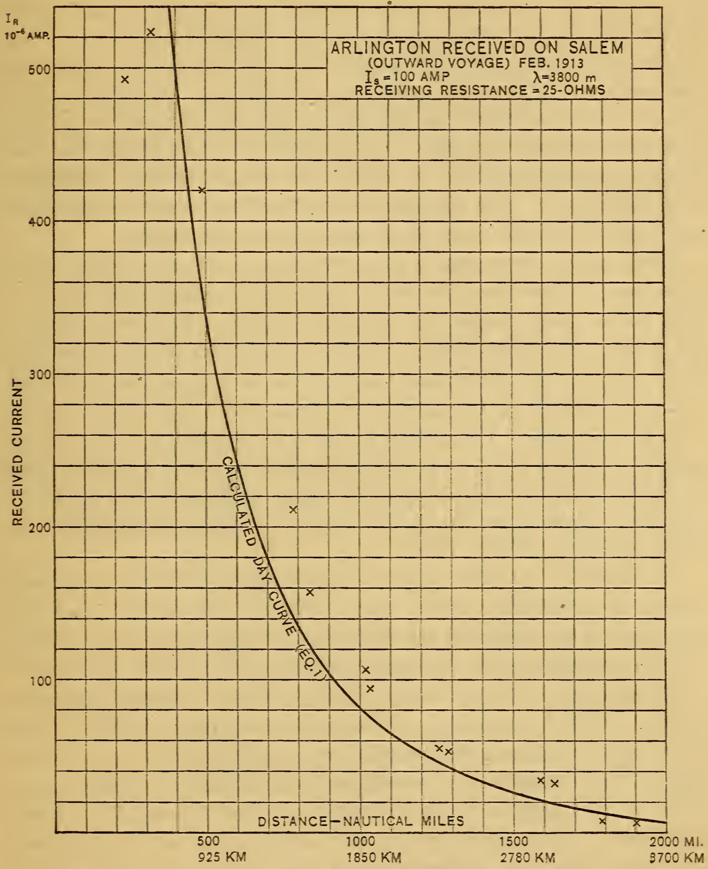

Fig. 1

taken as 7 microamperes through 25 ohms, instead of 10 microamperes. The observer was Mr. Lee, who also took the most important observations during the Brant Rock experiments. The curve of the figure is calculated from equation 1 or from Tables 16 and 16a of the report [16] on the Brant Rock work. Considering the difficulties of taking the measurements, and the assumption of a constant receiving resistance at all wave lengths (see p. 70, this article), the agreement between the calculated and observed values is excellent. It is especially to be noted that the signals became inaudible at almost the exact distance indicated by equation (1). The agreement is better than could be expected and must be looked upon as to some extent accidental.

Observations were made also during the return voyage from Gibraltar. Here the observed values lie considerably lower [17] than those taken during the outward voyage. They are, in fact, lower than any series which has been observed in our experiments. The two sets of observations are given in Fig. 2, the outward voyage values being indicated by crosses, and those of the return voyage by circles. The dotted curve in the figure gives the values calculated from the theoretical equation (4), but assuming the effective sending height of the Arlington antenna to be 61 m, as indicated approximately by the received current observations at the Washington Navy Yard.

In equation (1) and Fig. 1, the resistance of the receiving system is arbitrarily taken as 25 ohms. The actual receiving resistance of the Salem in the tests with Arlington at a wave length of 3800 m amounted to 50 ohms, distributed as follows: Resistance of inductance 25 ohms, antenna and ground 3 ohms, resistance due to coupled secondary for maximum signals 22 ohms. The decrement δ_1 was approximately 0.05, and δ_2 was 0.14. In the Brant Rock experiments the minimum audibility was determined to be 10.10^{-6} amp in terms of antenna current through 25 ohms resistance. This would give $2.5\ 10^{-9}$ watts in the receiving system. Assuming that the present telephones would give an audible response to a received current in the antenna of 7 10^{-6} amperes through 25 ohms, the energy required for an audible signal would

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[16] This bulletin, 7, p. 315; 1911.

[17] The observations during the return voyage were certainly taken much less carefully than during the outward voyage, partly because the official acceptance tests were finished, and partly because the exacting nature of the work over a long period had begun to tell on the strength of the operators.

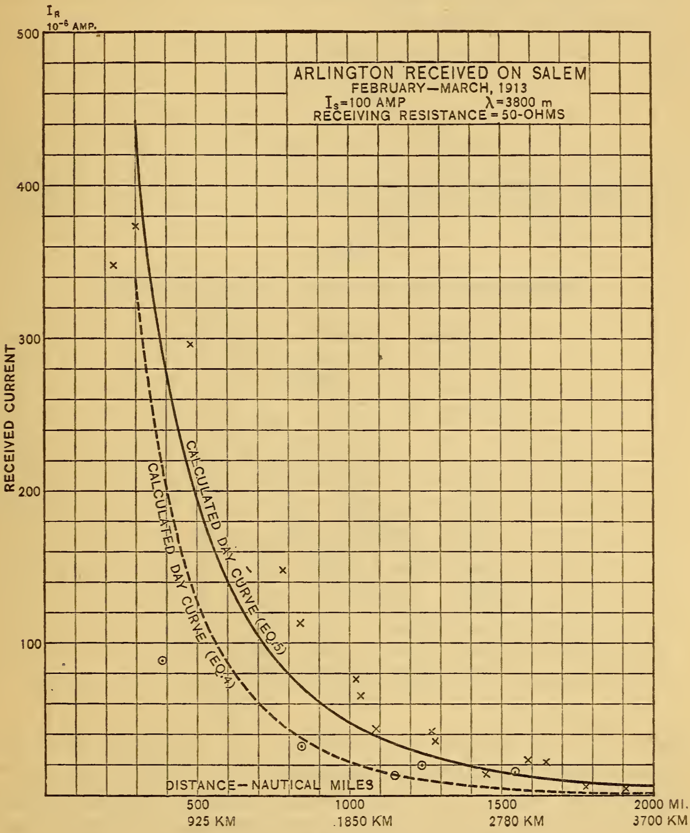

FIG. 2

be 12.25 x 10^{-10} watts. With this value of the energy required for audibility, and taking 50 ohms as the receiving resistance, the observed values of current in the receiving antenna are shown in column five of Table 2 and in the observed points of Fig. 2. The dotted curve of Fig. 2 and the third column of Table 2 have been calculated from equation (4).

$$I_R = 377 \frac{h_1 h_2 I_S}{\lambda d R \sqrt{1 + \frac{\delta_1}{\delta_2}}} e^{\frac{-0.0015d}{\sqrt{\lambda}}} \tag{5}$$

In column four of Table 2 and the solid curve of Fig. 2, are given the values of received current as calculated according to equation (5) which is the same as equation (4) except that the scattering term $e^{\frac{-0.0019d}{\sqrt[3]{\lambda}}}$ is replaced by the term $e^{\frac{-0.0015d}{\sqrt{\lambda}}}$ as derived from our Brant Rock experiments (equation (1)). There can be no doubt from these results that the theoretical equation (4) gives values too low to be reconciled with the observations, but that they are in very fair agreement with the semiempirical equation (5).[18]

TABLE 2

Arlington Received on the "Salem," February-March, 1913

Distance		Received current 10^{-6} amp.		
		Calculated		
Miles	Km	Eq. 4.	Eq. 5.	Obs.
300	556	335	431	410
400	740	200	278	300
500	925	128	195	225
600	1110	85.2	140	160
800	1480	40.7	79.0	95
1000	1850	20.7	47.6	59
1200	2220	11.0	29.7	34
1500	2780	4.42	15.3	19
2000	3700	1.07	5.65	5.0
2500	4630	0.28	2.20	....
3000	5560	0.074	0.89	....

Receiving observations were made also at Arlington with the Salem sending, the received currents at the distances beyond 450 miles (830 km) being measured by the calibrated detector method and the others by thermoelements. During the outward voyage no measurements were made except at 820 and 910 miles (1516 and 1684 km), but on the return voyage a fairly complete series was taken. The wave length used by the Salem was 2000 m, the antenna current on the outward voyage was 26 amperes, and on the return voyage 20 amperes. The observations are shown in Fig. 3, the outward values, reduced to 20 amperes radiation, are shown as crosses and the return observations as circles.

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[18] The currents received at any distance greater than 100 or 200 miles from the sending station often vary from day to day in a ratio of more than 2 to 1, quite apart from experimental errors. For this reason, only the observations beyond 1200 miles have any great weight in the relative validity of equations (4) and (5)

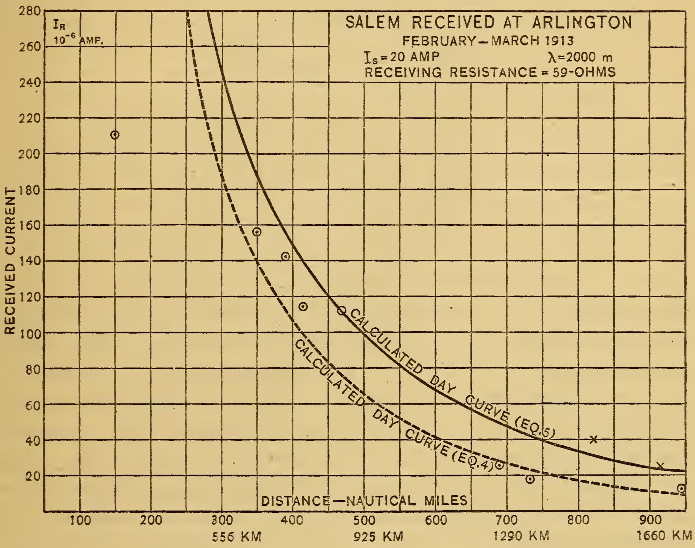

FIG. 3

The solid curve of Fig. 3 represents the calculated values for the received current as taken from equation (5), while the dotted curve is taken from the purely theoretical equation (4). At these distances the differences between equations (4) and (5) are so small that both curves appear to agree fairly well with the observed values.

OTHER OBSERVATIONS

From the many quantitative observations of the high frequency antenna current in sending and receiving made by the Navy Department, a few are collected in the following section.

They are intended to show the relation between the theoretical and observed values and also in some cases to indicate the effect of land absorption, especially as determined by wave length.

In Table 3 are given the data of a series of experiments carried on between the U. S. S. *Florida*, used as a sending station, and the United States naval radiotelegraphic laboratory, at Washington, used for receiving. The *Florida* during the time of the experiments lay near the entrance to Chesapeake Bay at a distance of about 130 miles from Washington. About two-thirds of this distance lay overland. The third column represents the values of received current calculated for transmission over salt water. The last column of the table which represents the ratio of observed to calculated received current, shows the increase of efficiency of transmission overland with increasing wave length, which agrees at least qualitatively with the theory. The calculated values of received current in the table are derived from the equation (5).

TABLE 3

U. S. S. "Florida" Received at the Bureau of Standards

λ meters	Received current 10^{-6} amp.		$\frac{\text{Obs.}}{\text{Cal.}}$
	Obs.	Cal. Eq. 5.	
750	44.8	295	0.15
1000	53.0	222	.24
1200	57.5	177	.33
1500	62.2	132	.47
2000	55.5	86.0	.65
2400	45.0	61.8	.73

$I_s=20$ amp $d=130$ miles (240 km) $h_1=39$ m. $h^2=30$m.

In Table 4 are given data regarding the navy yard stations at Philadelphia and Norfolk, received at the Bureau of Standards in autumn, and also Arlington received at St. Augustine in winter. This last shows how small the ground absorption may be at this distance for wave lengths of approximately 4000 m, being only a few per cent greater than that which would be expected over salt water.

TABLE 4

Sending station	Receiving station	λ meters	I_s amp.	Distance		h_1 meters	h_2 meters	R ohms	Received current 10^{-6} amp.		$\frac{\text{Obs.}}{\text{Cal.}}$
				Miles	Km				Obs.	Cal. Eq. 5.	
Philadelphia navy yard.	Bureau of Standards.	1000	10	100	185	39.0	30.0	69	76.8	239	0.32
Norfolk navy yard.	.....do........	1000	10	127	235	52.0	30.0	69	78.4	231	.34
Arlington spark.	St. Augustine	4100	90	530	980	*61	43.0	64	130.0	158	.80
Arc............	.....do........	4100	48	530	980	*61	43.0	53	85.0	108	.79

* h corrected from short-range observations.

COMPARISON OF ARC AND SPARK-SENDING APPARATUS

The question of the transmission efficiency of continuous and damped oscillations has caused much discussion between the adherents of the two methods. Several attempts have been made to settle this question by experiment, but over the moderate distances employed until recently no difference has been observed. In order to extend the observations to greater distances, two sets of experiments have been carried on from the Arlington station. For the first (winter of 1912–13) a 30-kw arc operated with 500-volt direct current was procured from the Federal Radiotelegraph & Telephone Co. At a wave length of 4100 m the arc gave an antenna current of approximately 50 amperes. At that time the regular spark-sending set of the station, operated at 1000 sparks per second, produced an antenna current of from 90 to 100 amperes. Careful measurements of received current were made at St. Augustine for the purpose of comparing the relative efficiency of the two methods of transmission. The results given in Table 4 indicate that at this distance, 530 nautical miles (980 km), no certain difference exists. These results were verified roughly by the shunted telephone method, using the slipping contact detector [19] at New Orleans and at Key West, both stations being approximately 900 nautical miles from Washington.

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[19] J. Wash. Acad., 1, p. 8, 1911.

Shortly afterwards, observations were made at the naval station at Colon, 1780 nautical miles from Arlington. During the two days on which observations were made, while both arc and spark signals were heard at night, the arc only was heard in the daytime. These observations indicated that at this distance the efficiency of transmission of the continuous waves was greater than that of the damped waves. During the voyage of the *Salem* to Gibraltar and return, which has already been mentioned, additional observations were made which indicated that the arc with half the antenna current, produced signals of practically the same intensity as the spark at 1500 to 2000 miles (2800 to 3700 km), as measured on the slipping contact detector, and actually seemed superior on the Fessenden heterodyne. Messages were continuously received with both arc and spark in the daytime up to 2100 miles (3900 km). Occasional signals were heard much farther, the arc being heard on one day in the daytime even in the harbor of Gibraltar. Both arc and spark were heard at night at all times during the voyage.

In order to make a comparison of the relative desirability of arc and spark transmission under summer conditions, a second series of observations was carried on between the Arlington station and Colon during the months of July and August, 1913. This time was chosen for the test on account of the fact that the signals are weakest at this period of the year, and at the same time the atmospheric disturbances are the strongest, so that the test may be considered as carried on under the most trying conditions.

For this work a 100-kw Poulsen arc belonging to the Universal Radio Syndicate was available for comparison with the regular rotary gap set of the Arlington station. The regular experiments began on July 25. The distance from Arlington to Colon is 1780 nautical miles (3300 km). From the formula deduced from the Brant Rock experiments, the Arlington signals, at a wave length of 4000 m, should be faintly audible at this distance, using a sensitive crystal detector and an antenna 180 feet high. As a matter of fact, the signals are just below audibility with ordinary detectors, as is shown from their strength on the more sensitive slipping contact detector. This fact may be due to the passage of the waves over Cuba, or to other conditions of transmission in this portion of the world.

The receiving work at Colon was done by Chief Electrician Meneratti, assistant at the naval radio laboratory. The receiving apparatus used consisted of a Federal receiving set, which is especially efficient at the longer wave lengths, a slipping contact detector, and a Fessenden heterodyne. The regular antenna of the Colon station, 180 feet (55 m) high and of about 0.0025 μf capacity, was used for the work.

The arc signals were sent out from Arlington at wave lengths of 4000, 5000, 6000, and 7000 m. Two wave lengths were used with the spark, 3500 m and 2500 m. The latter, however, proved so unsatisfactory at this distance that its use was abandoned after the first few days.

On account of the continuous atmospheric disturbances quantitative comparisons were of little value. The following table, Table 5, gives the number of schedules sent at the various wave lengths, and the corresponding number received.

TABLE 5

Comparison of Arc and Spark

	Wave length	Sending current amp.	Total schedules		Schedules heard	
			Day	Night	Day	Night
	m					
Spark	3500	104	9	0	7	0
Arc	4000	52	9	4	7	4
Arc	5000	60	0	4	0	4
Arc	6000	70	6	0	2	0
Arc	7000	78	3	7	3	7

The table shows that the best results were obtained with the arc at 7000 m, every schedule being successfully received. The same is true of the 5000-m arc waves, but in this case all the work was done at night, which prevents its being properly compared with the other schedules. The 4000-m arc and the 3500-m spark waves, which may be fairly compared, were received with the same degree of regularity and were of approximately the same strength as compared on the slipping contact detector, although the spark antenna current was double that of the arc. In this connection it must be remembered, as will be explained later, that while 80 per cent of the spark schedules were weakly audible on the heterodyne or slipping contact, practically none of the messages were readable. It appears from Meneratti's report that 50 per cent of all the arc messages sent at the various wave lengths, that is, 65 per cent of the arc schedules heard at all, would have been completely readable by double repetition. The very poor showing of the 6000-m wave, compared with the 4000 and 7000-m waves, is probably due to a defect in the receiver at this wave length.

One of the most interesting portions of the work was the study of the behavior of the slipping contact detector and heterodyne under the conditions of continuous atmospheric disturbances at Colon. The reports indicate that the heterodyne is somewhat more sensitive than the slipping contact, but that the difference is not very great. With spark signals the note produced by both is unmusical and difficult to distinguish from the atmospherics, and, as Meneratti remarks, both are inferior to a good crystal detector in receiving weak 500-cycle signals through continuous atmospherics. With arc signals, however, the case is entirely different. Here the slipping contact detector produces the same rustling sound as in the case of the spark, but the heterodyne produces a musical note of any pitch found most suitable for reading through the disturbances.

DISCUSSION OF RESULTS

The most important question which these experiments seek to solve is whether or not the theoretical formula (equation (2)) represents the observed facts of radio transmission. The first, or Hertzian, term of this formula agrees with the observations at short distances, but it is found that, for most of the land stations at least, the length of the equivalent oscillator is considerably less than twice the height of the antenna. The formula as a whole does not give satisfactory results at great distances, the scattering term apparently producing a diminution in electric intensity considerably greater than the observed values. In the Arlington-Salem experiments, at a distance of 3700 km, the strength of received current as calculated from the formula was only one-fifth of that actually observed, and would have reduced the signals below audibility at a distance of about 2600 km, while in reality they remained audible at 3700 km. A semiempirical expression for the received current was made up of a combination of the Hertzian portion of the theoretical formula with the absorption term from the purely empirical Brant Rock formula (equation 1). This expression, shown in equation 5, is in good agreement with the observations up to 3700 km at a wave length of 3800 m.

At present our observations on the transmission of different wave lengths over great distances are too meager in number to settle the question of the relation between the attenuation of the signals and the wave length. It is certain, however, that the attenuation even over sea water is very much decreased as the wave length is increased. It seems possible that, while the theoretical formula does not represent the facts at great distances, it would do so if all the energy withdrawn from the wave train, as represented by the scattering term, were actually lost. There is strong evidence,[20] however, that a portion of it again reaches the surface of the earth either by means of reflection or possibly refraction in the upper layers of the atmosphere. This reinforcement is undoubtedly very strong at night, producing the so-called night effects with their phenomenal distances of transmission. It is also probable that it plays an important part in the day time, increasing the transmission range, especially in winter, and also producing the irregularities in intensity frequently observed. If this be true, an additional term ought to be added to the theoretical formula. The experiments at moderate distances over land show a marked increase in ground absorption with decreasing wave length, at least qualitatively in accordance with the theory. For distances up to 2000 km, provided a wave length of more than 4000 m is used, ground absorption in most cases seems to nearly disappear, so that the transmission is almost identical with that over salt water. This is clearly shown at a distance of 980 km in the Arlington-St. Augustine experiments. (See Table

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[20] J. Washington Academy, 3, p. 284, 1913; Jahrbuch der drahtlosen Telegraphie, 7, p. 506, 1913; J. Washington Academy, 3, p. 326, 1913.

4.) The energy of overland night signals at moderate wave lengths appears to be transmitted mostly through the upper atmosphere, as the nature of the ground seems to have practically no influence.

The comparisons made of the efficiency of arc and spark transmission have indicated that, for distances of the order of 3700 km or more, continuous oscillations are on an average superior. The evidence is not complete enough to prove that this superiority always exists. It is apparently connected in some way with the reinforcement of the signals from the upper layers of the atmosphere, and is subject to the vagaries of this portion of the received energy. The indications seem to be that the superiority of the continuous oscillations is greater in winter than in summer.

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